Integrating design education across the curriculum using impromptu design projects

Abstract

In this paper, the use of impromptu design as a vehicle for integrating design education throughout the engineering curriculum is discussed. It is noted that engineering programs typically only offer engineering design experiences during freshman and senior year. To integrate design throughout the curriculum, the use of impromptu design exercises is currently being studied. Impromptu design exercises, often presented as contests, are commonly used as ice breakers at engineering student get-togethers. In a typical contest, students are given a simple design task capable of being completed in a short amount of time. The student team approaches the problem as they best see fit – this may include trial and error, design-build-test-redesign, and any number of different design approaches. When complete, the designs are tested to determine a “winner” based on some predetermined metric. Examples of impromptu design exercises currently being developed for a diverse range of classes across engineering disciplines are presented along with a discussion about some of the challenges of developing an adequate assessment plan. Relevant curriculum theory, such as that of Jerome Bruner’s spiral curriculum, will provide a backdrop for this discussion.

1. Introduction

In ABET’s 2010-2011 Criteria for Accrediting Engineering Programs\(^1\), engineering design plays a prominent role – ABET Criterion 3c states that “engineering programs must demonstrate that their graduates have an ability to design a system, component, or process to meet desired needs.” However, engineering programs typically only offer engineering design experiences during freshman and senior year [1, 2]; with little explicit engineering design education during sophomore and junior years while students are taking engineering science courses [3-5]. Thus, students’ opportunities to practice and learn design methodology are sporadic and disparate. These fragmented curricular experiences hinder student retention of knowledge related to engineering design, making them ultimately unprepared for jobs in design [3, 6-9]. If, as psychologist Jerome Bruner [10] suggests, learning constitutes a constructivist process in which students actively make content material their own, then students must be given multiple opportunities to interact in meaningful ways with that content (in this case, the engineering design process). The use of impromptu design projects across the curriculum provides one significant way in which to close this gap in students’ learning.

In order to overcome this issue, the use of the impromptu design contest format [6, 11, 12] to teach the engineering design process, while simultaneously reinforcing engineering science course content is presented. The impromptu design format is commonly used at engineering

\(^1\)The ABET criteria can be found at: www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2010-11%20EAC%20Criteria%201-27-10.pdf
student functions, like conferences and social meetings [6]. In a typical contest, students are given a simple design task capable of being completed in a short amount of time. The student team approaches the problem as they best see fit – this may include trial and error, design-build-test-redesign, and any number of different design approaches. When complete, the designs are tested to determine a “winner” based on some predetermined metric.

These contests can be seamlessly integrated into engineering science courses allowing an increase in student design capabilities, without the loss of engineering science content, thus enabling the integration of design throughout the curriculum. The educational novelty of this approach is twofold:

- First, the use of impromptu design exercises has mostly been limited to ice-breaker and team-building activities [6, 10]; we present preliminary results and ideas aimed at extending these exercises to directly teach the engineering design process. These exercises provide a unique opportunity to introduce beginning engineering students to and to reintroduce more experienced engineering students to the design process because of their direct, hands-on use of the design process.

- Second, the use of impromptu design exercises to reinforce course content allows for the integration of engineering design education into any engineering class without loss of a significant amount of class time. This makes the application of these projects feasible, even in engineering science classes where course schedules leave little time for design education [3].

Furthermore, this work represents one of the first efforts to systematically assess the value of impromptu design as a vehicle for engineering design education.

The rationale for including impromptu design projects in multiple courses is grounded in Bruner’s theory of a spiral curriculum. Reference [13] provides a helpful definition of spiral curriculum as, “an iterative revisiting of topics, subjects or themes throughout the course. A spiral curriculum is not simply the repetition of a topic taught. It requires also the deepening of it, with each successive encounter building on the previous one.” Integrating impromptu design projects into sophomore and junior courses means that engineering design will be “spiraled” throughout a student’s entire course of studies, thus bringing the curriculum into greater alignment. Reference [14] reported positive results from introducing a project-based spiral curriculum for chemical engineering students.

In this paper, examples of impromptu design exercises currently being developed for a diverse range of classes across engineering disciplines (Mechanical, Civil/Environmental, and Chemical) are presented, followed by instructor comments and observations, and a discussion of the challenges involved in developing an adequate assessment plan.
2. Background

In ABET’s 2010-2011 Criteria for Accrediting Engineering Programs, engineering design is defined as:

… the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

Engineering design education plays a key role in all engineering disciplines, as seen by its prominence in ABET’s criteria. With this in mind, there has been a significant push over the past years to integrate engineering design throughout the engineering curriculum. While there has been some success with techniques like the incorporation of engineering design projects in engineering science courses, the use of junior-level design competitions, and the integration of undergraduate students (at all levels) into the senior design process, it is difficult to emphasize design education into engineering science course, while at the same time covering all the important theoretical content necessary to train successful engineers – it is noted that this is a niche for impromptu design projects.

2.1 Impromptu Design Projects:

Impromptu design exercises (often presented as contests) are commonly used as ice-breakers at engineering student gatherings. In a typical impromptu design exercise, students are given a simple design task capable of being completed in a short amount of time, for example 15 minutes or one class period. The student team approaches the problem as they best see fit – this may include trial and error, design-build-test-redesign, and any number of different approaches. When complete, the designs are tested to determine a “winner” based on some predetermined metric.

2.1.1 Motivation for the use of Impromptu Design Exercises: The educational research on design education is specifically focused on design as a behavior – that is to say that the act of design is a set of actions that the engineer does. Thus, in order to develop this behavior, engineering students require a significant amount of design practice, along with proper reinforcement – one suggestion is that several simple design problems precede the larger capstone design project. In addition, design and other engineering subjects are best learnt through hands on active learning, e.g. project based learning. Therefore, the integration of impromptu design exercises into all aspects of the curriculum is motivated by the above research findings.

2.1.2 Use of impromptu design contests in university classrooms: Aside from using impromptu design contests in university courses as ice-breakers, little research has been carried out on using impromptu design to achieve desired education outcomes. The current research in this area has focused on the ability of impromptu design contests to foster creative thinking and team building – it is noted that they have been proven quite effective in this regard.
Preliminary findings regarding the use of impromptu design as a vehicle for engineering design education show promise – this preliminary work was carried out by author Clayton [11], and is summarized below.

2.1.3 Example impromptu design contest: The following impromptu design problem has been used as an ice-breaker/team-building/design-education exercise in freshman and sophomore level design courses at Seattle University and Villanova University [11]. It should be noted that this project was originally adapted from an American Society of Mechanical Engineers (ASME) website which is no longer available and is thus, not provided as a reference.

The general premise of this example impromptu design project is to design and build a truss structure using marshmallows and straws. At Seattle University, the sophomore students were given the following problem:

Need Statement: Street Performers in rain-prone areas (e.g. Pike Place Market in Seattle, WA) need a way to keep their tip cups off the ground.

Problem: Design a tip cup holding device from straws and marshmallows.

Scoring Metric: Distance from the bottom of the cup to the bottom of the truss structure in inches (h) multiplied by the number of pennies the cup can hold (N), i.e.

\[ \text{Score} = h \times N. \]

Overall student response to the project has been positive [11]. Figure 1 shows pictures of some of the student designs.

In addition to the problem statement, students were given a plastic Ziploc bag containing 20 straws, 10 marshmallows, a roll of pennies and a Styrofoam cup. Also available to the students were scissors and additional pennies. The amount of time the students have available to them is flexible and depends on the setting – for example in-class projects must be completed with time left for reflection.

The instructor’s role in impromptu design contests is to give the problem statement, hand out the materials, and then step back and let the students design and build. The only other instructor responsibilities are to clarify rules (for example, in the design contest described above, students tend to ask if they can incorporate the Ziploc bag into their design) and to make sure the students are aware of time constraints.
2.2 Impromptu Design as a Design Education Tool

Impromptu design contests, as described in section 2, provide a fun exercise that facilitates team building and creative thinking. With some guided discussions, these contests can be extended to provide an excellent introduction to the engineering design process. The content of this guided discussion is presented below.

Following the impromptu design contest, students are asked,

“What steps did you follow as you built your … (truss structure for example)?”

Students are given time to reflect on this question both individually and in groups. Each group is then asked to make a list of steps it followed when solving the design problem. In doing this, they are developing a model of the engineering design process they followed. Finally, the student teams are asked to share their individual design models with the class. When the discussion about the different design approaches is complete, a short lecture about different models of the design process can be used to help solidify the impromptu design’s introduction to the design process.
3. Bringing Impromptu Design to Engineering Science Classes

In the following, examples of how the impromptu design format can be extended to reinforce content in engineering science courses are presented, along with details of how the projects will be tested.

3.1 Example 1 – Mechanical Engineering 5411: Mechatronics: Mechatronics is a senior elective which usually has 30 students. The Villanova course catalog description of this 3 credit course is as follows:

   Introduction to mechatronics, mechatronics components, its working principle and models, digital and analog electronics, mechatronic actuators, microcontrollers, sensors, and modeling mechatronic systems.

It is important to note that this course typically includes a semester long design project. However, this project is often done without consideration of the engineering design process, i.e. students proceed with their designs without reflecting on the design aspects of the project. Therefore, this class will significantly benefit from the introduction of impromptu design exercises.

An example impromptu design project that might be implemented in this class is as follows:

| Need Statement: Hot coffee can cause serious burns and thus needs to have its temperature monitored |
| Problem: Design a temperature measurement system that can measure coffee temperature. |
| Scoring Metric: The design will be judged based on their accuracy (when compared to a mercury thermometer) over a range of temperatures from ice-water to hot coffee. |

The supplied materials will be various temperature sensors (thermistors, thermocouples, etc.), standard electronics equipment (resistors, capacitors, hookup wire etc.) and a microcontroller prototyping board. With this equipment, the students would be expected to design and build the sensor circuitry and program the microprocessor to read the sensor and display the temperature. This exercise directly reinforces course content, as seen in the course description, as this class has a focus on sensors, circuits, and microcontrollers.

3.2 Example 2 – Civil and Environmental Engineering 2106: Mechanics II: Mechanics II (CEE 2106) is a required sophomore class with 50 to 60 students divided in two sections (usually less than 30 students in each section). This 4 credit class covers the following topics:
The materials aspects of this course are of great importance, not only to this course, but to future design classes as well; however students often lack the proper link between material properties and the design aspects of civil engineering projects. As such, an impromptu design exercise is an excellent tool, allowing students to develop better understanding of a holistic design approach. With current needs for environmentally friendly infrastructure development\(^2\), the demand for sustainable concrete materials (concrete is a second most widely used material in the world after water) is even more pronounced. Consequently, the students’ learning process will greatly benefit from the application of an impromptu exercise in the lesson focused on concrete mixture design development.

An example impromptu design project that might be implemented in this class is as follows:

| Need Statement: A new high-rise building is being constructed in Philadelphia. Concrete compressive strength requirements need to be met for the material to be accepted at the construction site. |
| Problem: Design a concrete mixture that will maximize the strength while minimizing the cost of the mixture. |
| Scoring Metric: The design will be judged based on the maximum compressive strength \((f'_{c})\) and minimum cost of the mixture, following the final score formula: |

\[
\text{Final Score} = (75*f'_{c}/f'_{c,max}) - (25*\text{Price}/\text{P}_{\text{min}}) 
\]

Materials provided to students will be equal amounts (for example 200g) of: cement, water, fine aggregate (sand) and coarse aggregate (gravel). Using these four basic concrete constituents, students will be asked to proportion and mix materials together to obtain a mixture that can be poured and placed into a cubic mold. Once the proportioning steps and pouring is completed, students will be asked to provide the amounts of materials used and mixing sequence they followed. During the next class meeting, students will be able to test their cubes under compression and determine strength of the concrete they designed. The class discussion will follow comparing different results obtained.

3.3 Example 3 – Chemical Engineering 5534: Biomaterials: Biomaterials is a junior/senior level elective course open to all engineering students. It is largely filled with chemical and some

\(^2\) For example see the ASCE report card at [www.infrastructurereportcard.org/](http://www.infrastructurereportcard.org/)
mechanical engineering students with enrollment capped at 25 students. The course description from the Villanova course catalogue is as follows:

Materials for use in medicine and in/on the body, material bulk and surface properties, biological responses to materials, applications, manufacturing processes, cost, sterilization, packaging and regulatory issues.

The course begins with a review of materials science since it is not a required course for the chemical engineering students. Students are introduced to both bulk and surface material properties and how to evaluate them. The students then learn about biocompatibility, and how the material reacts when in contact with human tissue. A sample impromptu design that will be implemented in this course is a design of an artificial heart valve. Students will be instructed on the anatomy and function of a normal human heart prior to learning valvular diseases.

The following design problem will be given:

<table>
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<tr>
<th>Need Statement: The human heart has four valves that open and close to control the flow of blood allowing it to move in one direction only. Many times these valves will fail either from a congenital heart defect, age or illness.</th>
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<tr>
<td>Problem: Using the provided materials, design a valve that will allow the blood to flow in one direction only. Make sure to think of ways to ensure the biocompatibility of this design (and how to sterilize!)</td>
</tr>
<tr>
<td>Scoring Metric: Design will be evaluated based on its ability to prevent back-flow and their effort to ensure biocompatibility and sterile process.</td>
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<tr>
<td>Final Score= 20% Sterility + 30% prevention of clots + 50% prevent back-flow</td>
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</table>

The instructor will provide different supplies to make a mechanical valve replacement. Materials will range from soft textiles, hard metals, and rubbery plastics. This will allow the students some creativity in combining the materials to imitate the complexity of the actual human heart valve. The students will be able to test their design with a pump set up to check its efficacy at preventing back flow. The design teams will also need to prepare ideas of how to sterilize the material and suggest improvements to prevent blood clot adhesion when the material comes in contact with human blood (this will not be tested due to feasibility).

A follow-up assignment on the cost of the design improvements versus the price to produce will be given. Students will need to determine the cost of their design, the improvements they add for decreased clotting and sterility. The assignment then assumes your company will only produce this design if you can produce a profit of $X. (which will be set to ensure the designs are under this amount) The students are asked to use the NSPE code of ethics to evaluate their decision for recommended use of the product and the company’s decision to produce the valve only for a
profit of $X. This goes along with the Chemical Engineering Department’s push to include Ethics throughout the curriculum.

3.4 Implemented Project: Ice-cream

The following project was given on day one of CHE 3031 Heat Transfer Operations, a required junior level Chemical Engineering course. The assignment was as follows:

Using the given materials, create a device to turn the ice-cream solution into actual ice-cream (freeze the half-and-half) within the 30 minutes provided. Students were to write up a short summary of what they did, including a diagram, and how it worked.

The materials provided were:

Ice-cream mixture: half & half, sugar, vanilla extract (cold, ~40°C)

Building materials: Plastic water bottles, plastic food storage boxes (various sizes), plastic zip-top bags (sandwich and quart size), aluminum foil, plastic wrap, duct tape, masking tape, coffee cans (metal), 1 gallon milk jugs, other assorted recyclable plastic containers

Coolant: Ice, water, salt (table and rock)

All student groups (2-3 students per group) were able to create a method to freeze the ice cream. Most did not think to mix it very well - so there resulting ice cream didn’t taste as good. Also many groups added too much salt, and didn’t seal their containers very well, so they ended up with salt within their ice cream (also didn’t taste very good). The major disappointment for the instructor was the lack of creativity in the first section. Two classes (30 students each) both did
the same impromptu design with different results. The first section all followed the idea of one group who used a small zip-top bag inside a larger bag with ice and some salt. Their lack of creativity was a disappointment, and maybe more physical space separating the groups and the supplies might have helped. All of the supplies were up front on a table, and all groups gathered around to collect what they wanted (thus the copy cat effect was seen). The second section of students, however, was surprisingly more creative in their efforts. They used the coffee cans for outer material so they could roll them, they sealed their containers with the tape provided, and in general had many different looking containers. The design experience next time might be improved by giving each group only select materials to have to work with—thus forcing more creativity in their designs.

4. Assessment Plan

Assessment of these projects is currently being developed and plans to employ diagnostic, formative, and summative assessments. These assessment measures will investigate students’ knowledge of the engineering design process as well as their ability to apply course content to impromptu design exercises. In addition, the assessment plan will gain insight into the curricular decisions of the faculty members incorporating impromptu design exercises into their courses. Both quantitative and qualitative data will be used to determine the achievement of the research outcomes. Quantitative data will include pre- and post-course surveys and pre- and post-course tests of students’ knowledge and understanding of both the engineering design process and course content. Interviews with course instructors and in-class observations of students engaged in impromptu design exercises represent the qualitative measures to be employed in the study. The methods and procedures for data collection and analysis are detailed below.

5. Conclusion

In this paper, the use of impromptu design as a vehicle for integrating design education throughout the engineering curriculum was discussed. Examples of impromptu design exercises currently being developed for a diverse range of classes across engineering disciplines were presented along with a discussion about some of the challenges of developing an adequate assessment plan.

Bibliography


